

**LABORATORY MEASUREMENTS OF SO<sub>2</sub> AND N<sub>2</sub> ABSORPTION  
SPECTRA FOR PLANETARY ATMOSPHERES**

**A Final Summary of Research** for the period 3/1/2000 – 2/28/2003

Principal Investigator: Glenn Stark

Institutional Address: Physics Department  
Wellesley College  
Wellesley, MA 02481  
(781-283-3108)  
([gstark@wellesley.edu](mailto:gstark@wellesley.edu))

NASA Planetary Atmospheres grant number: NAG5-9059

Date Submitted: July 8, 2003

Our laboratory projects supported by NASA Planetary Atmospheres grant NAG5-9059 focused on the measurement of SO<sub>2</sub> ultraviolet absorption cross sections and the measurement of VUV N<sub>2</sub> band and line *f*-values and line widths in the 80 to 100 nm region. Our accomplishments for these projects are summarized below:

### 1. SO<sub>2</sub> Absorption Cross Sections

We continued our program of SO<sub>2</sub> absorption cross section measurements on the Imperial College vacuum ultraviolet Fourier transform spectrometer. The work was carried out in collaboration with Dr. Anne Thorne and Dr. Juliet Pickering of Imperial College, London, and Dr. James Rufus of the Harvard-Smithsonian Center for Astrophysics.

During this reporting period we completed the following tasks:

- (a) SO<sub>2</sub> cross sections in the 198 – 220 nm region were measured at a temperature of 160 K. A number of problems in the data reduction and analysis, relating to the determination of background intensity levels in the absorption measurements, were addressed and successfully resolved. A manuscript is in preparation.
- (b) A complete set of room temperature cross section measurements spanning the 220 – 325 nm spectral region was planned, undertaken, and completed.
- (c) The reduction and analysis of the room temperature measurements was undertaken and completed. A manuscript was published in the *Journal of Geophysical Research* (2003).
- (d) Our SO<sub>2</sub> cross section data was archived and made available to the planetary atmospheres community through our data website:  
<http://cfa-www.harvard.edu/amdata/ampdata/cfamols.html>

Publications and conference presentations:

*High resolution photoabsorption cross section measurements of SO<sub>2</sub>, II: 220 to 325 nm at 295 K*, J. Rufus, G. Stark, P. L. Smith, J. C. Pickering, and A. P. Thorne, *J. Geophys. Res.* 108 (E2) 10.1029/2002JE1931 (2003).

*UV photoabsorption cross sections of CO, N<sub>2</sub>, and SO<sub>2</sub> for studies of the ISM and planetary atmospheres*, P. L. Smith, G. Stark, K. Yoshino, J. Rufus, J. C. Pickering, A. P. Thorne, and W. H. Parkinson, NASA Laboratory Astrophysics Workshop, NASA Ames Laboratory (2002).

*High resolution photoabsorption cross section measurements of SO<sub>2</sub> at 295 K between 220 and 328 nm*, P. L. Smith, J. Rufus, G. Stark, A. P. Thorne, and J. C. Pickering, 33<sup>rd</sup> Annual AAS Division for Planetary Sciences Meeting, New Orleans, LA (2001).

*High resolution UV SO<sub>2</sub> absorption cross sections and VUV N<sub>2</sub> oscillator strengths for planetary atmospheres studies*, P. L. Smith and G. Stark, 32<sup>nd</sup> Annual AAS Division for Planetary Sciences Meeting, Pasadena, CA (2000).

*A model for a new type of molecular atlas*, P. L. Smith, G. Stark, K. Yoshino, K. P. Huber, and A. Springsteen, 2<sup>nd</sup> International Conference on Atomic and Molecular Data and Their Applications, Keble College, Oxford, England (2000).

*High-resolution UV absorption studies of N<sub>2</sub> and SO<sub>2</sub>*, P. L. Smith, G. Stark, J. Rufus, J. C. Pickering, and A. P. Thorne, 24<sup>th</sup> International Astronomical Union General Assembly, Manchester, England (2000).

## **2. N<sub>2</sub> Band and Line Oscillator Strengths and Line Widths**

We continued our program for determining oscillator strengths and line widths of N<sub>2</sub> bands in the 80-100 nm region. Through collaborations with Dr. Klaus Huber (National Research Council, Ottawa, Canada), Dr. Kouichi Yoshino (Harvard-Smithsonian Center for Astrophysics), and Professor K. Ito (Photon Factory, KEK), we have an established measurement program at the Photon Factory synchrotron facility in Tsukuba, Japan. The Photon Factory VUV beamline is equipped with the highest-resolution photoelectric VUV spectrometer in the world and has an exceptionally stable synchrotron radiation source, making it an ideal facility for our N<sub>2</sub> measurements.

The following work was completed in this reporting period:

- (a) Analysis of room temperature data for twelve absorption bands in the 94 – 100 nm region. Emphasis was on the determination of line widths in strongly predissociating bands. The level of detail in the analysis varied from band to band. The highest level of scrutiny involved applying a line shape fitting routine to individual rotational lines – this approach was taken for bands of particular astronomical interest.
- (b) A collaboration with Dr. Leslie Young (SWRI) was established to assist in the interpretation of Voyager occultation observations of Triton. We provided Dr. Young with N<sub>2</sub> transmission models based on our new analyses of our laboratory absorption data.
- (c) The analysis of supersonic jet absorption measurements of the congested spectral region from 80 – 86 nm was used in concert with theoretical models of the near-threshold region to interpret the strongly perturbed spectra. This work was completed in collaboration with Dr. K. P. Huber (National Research Council, Canada) and Prof. Ch. Jungen (Universite de Paris-Sud, France). A manuscript was published in the *Journal of Chemical Physics* (2003).
- (d) We established a new collaboration to further the theoretical modeling of N<sub>2</sub> band f-values and predissociation line widths with B. R. Lewis and S. T. Gibson (Australian National University) and W. Ubachs (Vrije Universiteit, The Netherlands).
- (e) We continued to maintain and update our on-line spectroscopic atlas for N<sub>2</sub> absorption features between 80 – 100 nm:

(<http://cfa-www.harvard.edu/amdata/ampdata/N2ARCHIVE/n2home.html>).

This site contains information on line positions, spectroscopic identifications, line strengths, and line widths for the <sup>14</sup>N<sub>2</sub> molecule and its isotopic variants. The listings are searchable (e.g., by wavelength interval or band identification) and able to be down-loaded in a convenient format.

Publications and conference presentations:

*The near-threshold absorption spectrum of N<sub>2</sub>*, K. P. Huber, Ch. Jungen, M. Jungen, and G. Stark, *J. Chem. Phys.* 118, 4517 (2003).

- Triton's atmosphere in 1989: new lab data, new profiles*, L. A. Young, G. Stark & R. J. Vervack, 34<sup>th</sup> Annual DPS Meeting, Birmingham, AL (2002).
- UV photoabsorption cross sections of CO, N<sub>2</sub>, and SO<sub>2</sub> for studies of the ISM and planetary atmospheres*, P. L. Smith, G. Stark, K. Yoshino, J. Rufus, J. C. Pickering, A. P. Thorne, and W. H. Parkinson, NASA Laboratory Astrophysics Workshop, NASA Ames Laboratory (2002).
- Vacuum ultraviolet molecular nitrogen photoabsorption cross sections for planetary atmospheric transmission models*, G. Stark, P. L. Smith, K. Yoshino, J. Rufus, and K. P. Huber, 33<sup>rd</sup> Annual AAS Division for Planetary Sciences Meeting, New Orleans, LA (2001).
- Rovibronic structures of nitrogen at near-threshold energies*, K. P. Huber, Ch. Jungen, and G. Stark, International Conference on Spectroscopy in the 21<sup>st</sup> Century, Kanagawa, Japan (2001).
- Line oscillator strength measurements in the 0-0 band of the c<sub>4</sub>' – X transition of N<sub>2</sub>*, G. Stark, K. P. Huber, M.-C. Chan, T. Matsui, P. L. Smith, and K. Ito, Annual Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society, Storrs, CT (2000).
- High-resolution UV absorption studies of N<sub>2</sub> and SO<sub>2</sub>*, P. L. Smith, G. Stark, J. Rufus, J. C. Pickering, and A. P. Thorne, 24<sup>th</sup> International Astronomical Union General Assembly, Manchester, England (2000).
- Line oscillator strength measurements in the 0-0 band of the c<sub>4</sub>' <sup>1</sup>Σ<sub>u</sub><sup>+</sup> ← X <sup>1</sup>Σ<sub>g</sub><sup>+</sup> transition of N<sub>2</sub>*, G. Stark, K. P. Huber, K. Yoshino, M.-C. Chan, T. Matsui, P. L. Smith, and K. Ito, Astrophysical Journal 531, 321–328 (2000).